Correlation of Test Data From Some NIF Small Optical Components

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U.S. Department of Energy June 12, 2001

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Correlation of test data from some NIF small optical components

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ABSTRACT

The NIF injection laser system requires over 8000 precision optical components. Two special requirements for such optics are wavefront and laser damage threshold.

Wavefront gradient is an important specification on the NIF ILS optics. The gradient affects the spot size and, in the second order, the contrast ratio of the laser beam. Wavefront errors are specified in terms of peak-to-valley, rms, and rms gradient, with filtering requirements. Typical values are lambda/8 PV, lambda/30 rms, and lambda/30/cm rms gradient determined after filtering for spatial periods greater than 2mm. One objective of this study is to determine whether commercial software supplied with common phase measuring interferometers can filter, perform the gradient analysis, and produce numbers comparable to that by CVOS, the LLNL wavefront analysis application.

Laser survivability of optics is another important specification for the operational longevity of the laser system. Another objective of this study is to find alternate laser damage test facilities. The addition of non-NIF testing would allow coating suppliers to optimize their processes according to their test plans and NIF integrators to validate the coatings from their sub-tiered suppliers. The maximum level required for anti-reflective, 45-degree high reflector, and polarizer coatings are 20, 30, and 5 J/cm^2 (1064nm, 3ns pulse-width), respectively. The damage threshold correlation between a common set of samples tested by LLNL and a commercial test service is given.

Key Words: interferometry, wavefront gradient, laser damage

1. INTRODUCTION

The National Ignition Facility (NIF) is a project funded through the Department of Energy. The NIF Project is a 192-beam, 1.8 MJ experimental laser facility under construction in Livermore, CA. This unique facility will access regimes of extreme pressures and temperatures. The NIF has missions to serve the national security, energy, and basic science community. The NIF building is over 95% completed. After the installation of the laser beam transport infrastructure and support equipment, the building will be available for deployment of optical components.

The NIF injection laser system (ILS) requires over 8000 precision optical components. The ILS optics have dimensions ranging from about 25 mm to a maximum of 150 mm in diameter. The optics are expected to be manufactured by custom optical fabrication and coating suppliers. Initial procurement of the ILS optical components for Early Risk Mitigation Activity Milestones has begun. In preparation for this activity, test procedures of certain crucial component requirements were evaluated. Two special requirements for such optics are measurements of the residual wavefront errors and the laser damage thresholds. The ILS optics meeting these requirements would assure the beam quality of the laser beam. The studies used commercially available measurement tools and services, and compared the results to those obtained with NIF project equipment.

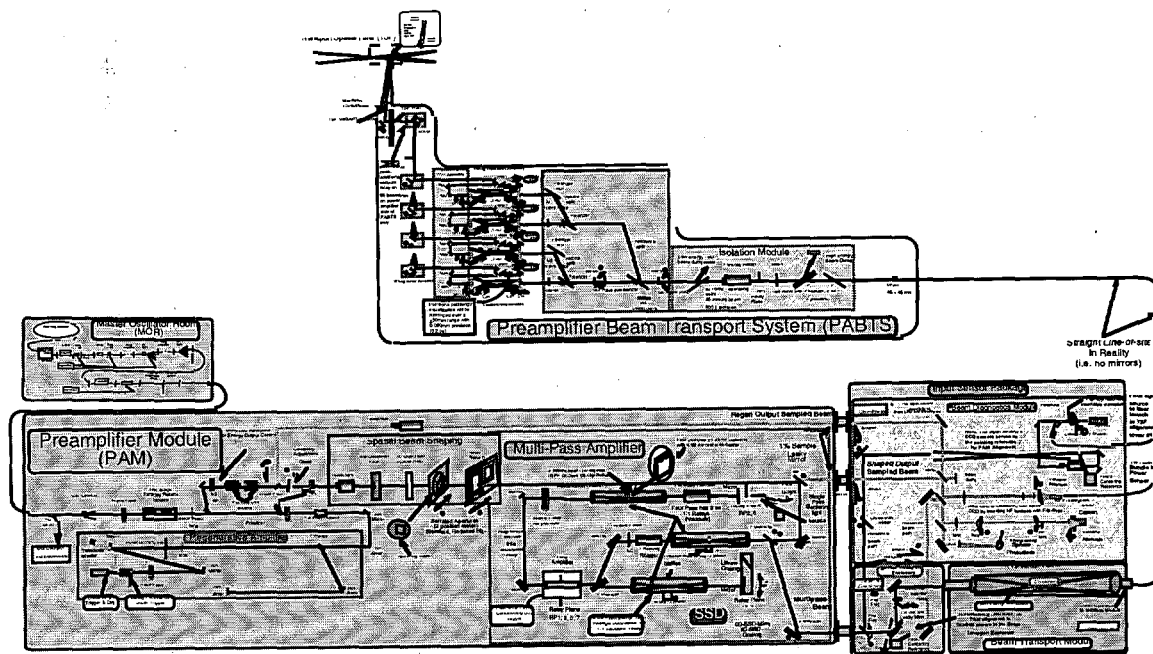Figure 1 Sketch of the NIF injection laser system. The ILS consists of the Master oscillator, Pre-amplifier, Input Sensor transport, Pre-amplifier transport, and injection telescope sub-systems. There are 48 ILS systems in NIF.
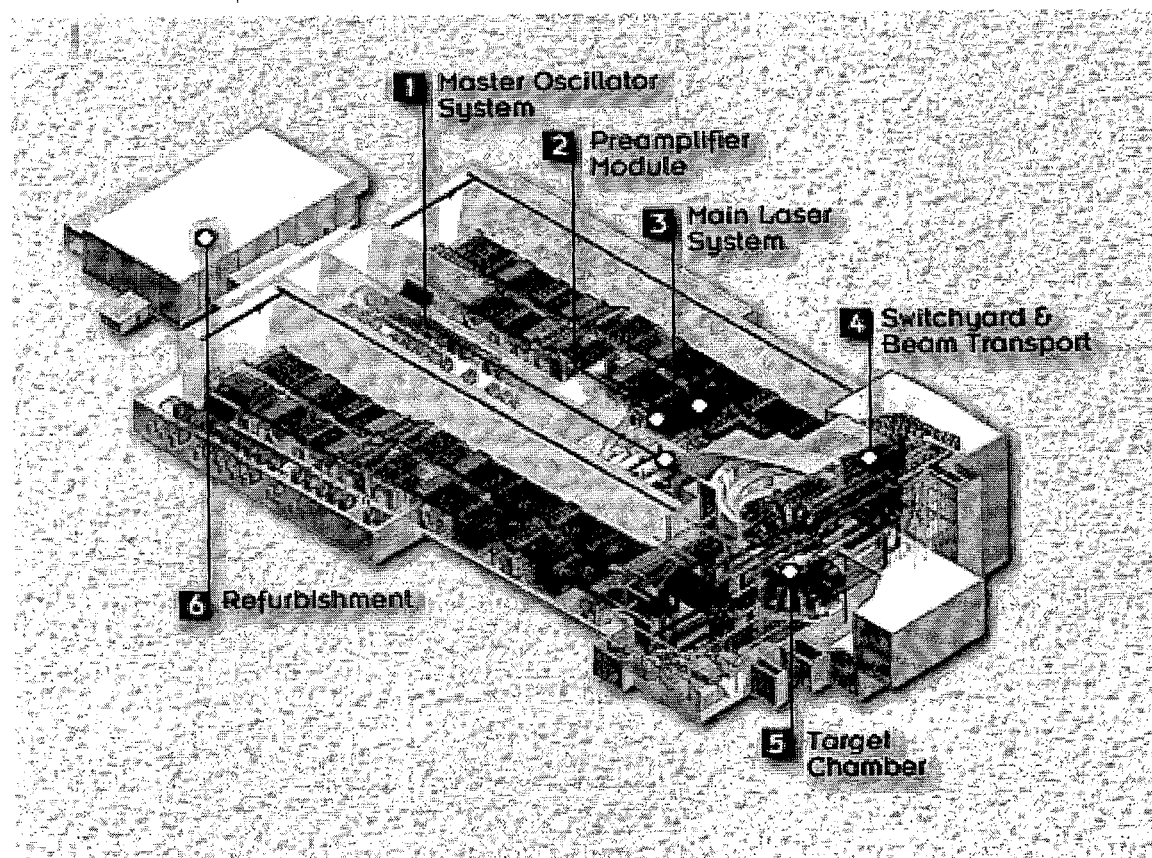

Figure 2 Location of the injection laser systems in the NIF. The Master oscillator system and Preamplifier module comprise the first two sections of the injection laser system.

In the ILS, 48 individual laser beams are amplified over 10^9 times, each beam is split into 4 other beams, and injected into the main amplifiers (Figure 1). The beams travel over 400 meters and are aligned with each other into a 500 μm diameter target spot (Figure 2).

The ILS optics are specified stringently because wavefront aberrations generated in the ILS system cannot be filtered out in the main laser system. ILS wavefront aberrations affect the overall quality of the beam at the target plane. Accumulation of the ILS wavefront errors degrades the beam contrast, a measure of the fluence uniformity. A beam with high contrast has hot spots that raises the risk of laser damage for downstream optics (Figure 3). The objective of one portion of this study was to determine whether the software supplied with common phase measuring interferometers can filter, perform the gradient analysis, and produce numbers comparable to that by the LLNL wavefront analysis application, Custom Viewer for Optical Specifications (CVOS).

| Low Contrast Beam | High Contrast Beam |
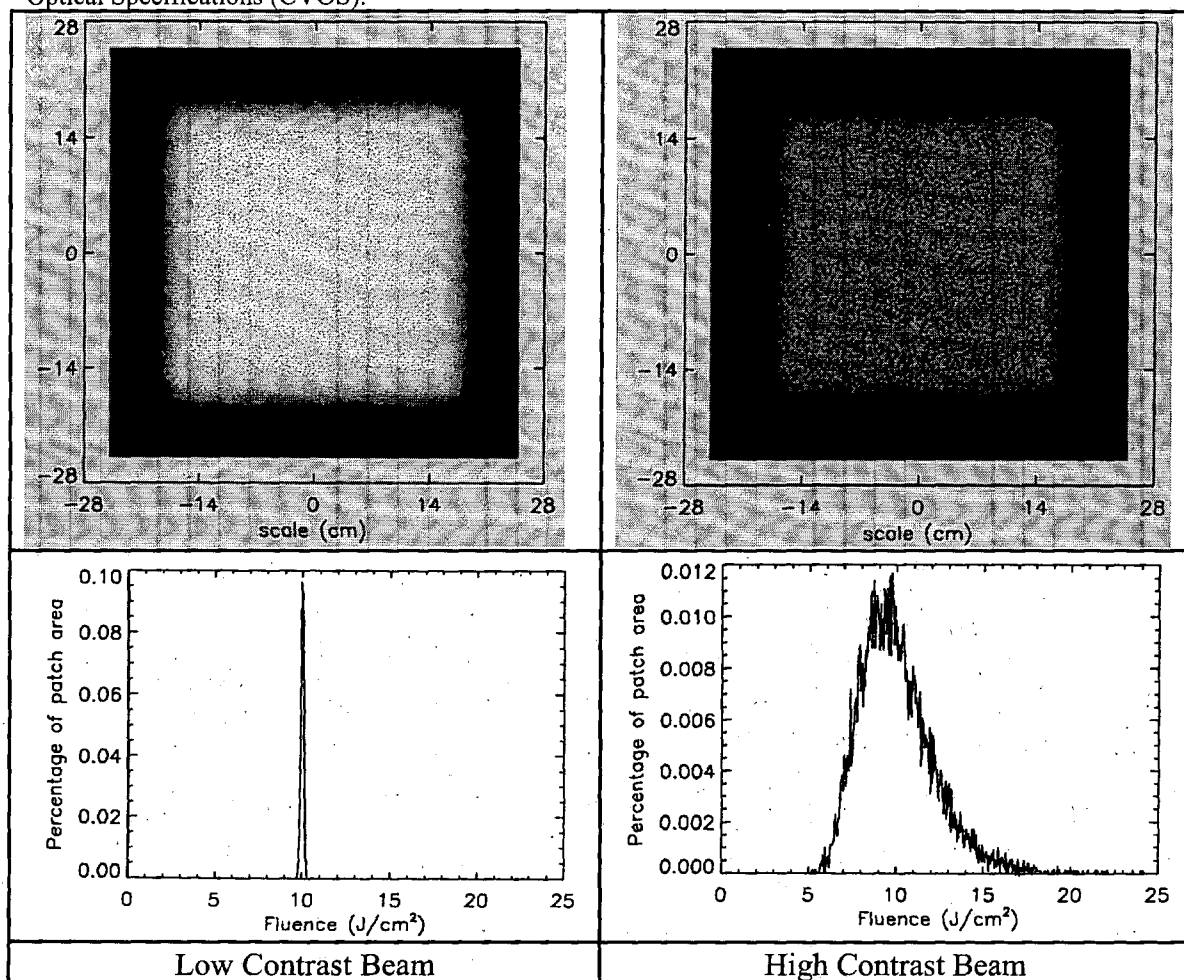
Figure 3 Beam contrast simulation results from PROP92 code. Laser beams have the same average fluence. The top row is the surface map of the beam fluences. The bottom row has the plots of the number of pixels at a given fluence. A low contrast beam has a more uniform fluence across the beam footprint.

Laser survivability of optics is another important specification for the operational longevity of the ILS system. The ILS optics are not designed to be items serviced on a regular basis. Qualification of a commercial service for laser damage testing has many advantages for coating suppliers. There should be quicker turn-around of laser damage thresholds for process development. Coating suppliers have the option of determining the survivability of their coatings without revealing the optimization history with their customer. Finally, an independent party is available for laser damage threshold evaluation.

2. EXPERIMENTAL SET-UPS

2.1 Wavefront Test

Four high reflectors (HRs) were measured at normal- and use-angle incidences using a Zygo (633 nm) Mark GP1xps interferometer. This is the interferometer has a 640x480 pixel camera and is situated in a plexiglass enclosure to minimize air turbulence. The HRs are designed to reflect 1053 nm light and at a 45 degree angle-of-incidence. Typical interferometric data is given in Figure 4. The reflected wavefronts from the optics were collected, spatial frequencies less than 2 mm were filtered out, the rms wavefront values recorded, and finally analyzed for the rms gradient. Table 1 summarizes electronic file names according to the serial numbers and test angle.

Table 1 Electronic file names of interferometric data high reflector coatings.

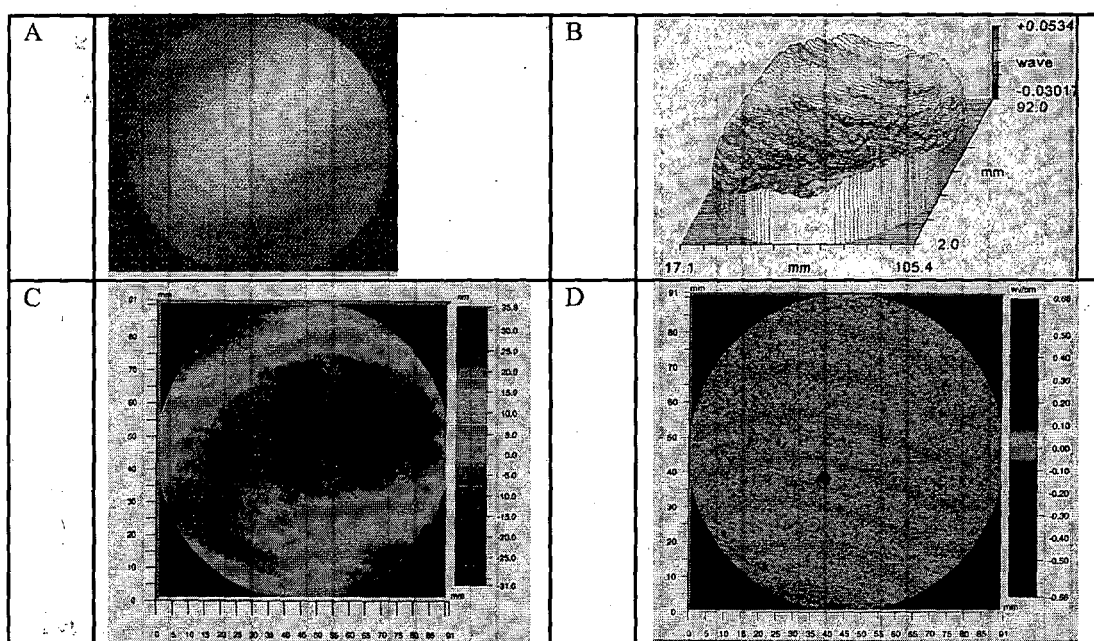| Serial Number	Near normal	Use-angle
961003	8031	8041
961004	8032	8042
961005	8033	8043
961010	8034	8044

Figure 4 Interferometry of the high reflector SN961004. A. Obtain the wavefront data. B. View the reflected wavefront. C. Filter the wavefront to keep spatial frequencies greater than 2 mm. D. Analyze for the gradient in the X and Y coordinates.

The wavefront rms and gradient analysis was performed only with this set of data in order to eliminate test effects between interferometers (with one exception). The baseline wavefront filtering and gradient standard was determined with the LLNL application, CVOS. Other filtering and gradient analysis were performed using the software applications designated as Px.v.w and Ux.v.w, and Vx.v.w, where x.v.w stands for the version software all cases. The software versions evaluated typically represent the most current available at the time.

The exception to the rule where the gradient is analyzed on a data set different from Table 1 is the case of U6.0.26. The mirror with serial number 961003 and the LLNL return flat, serial number 2, was taken to an off-site optical fabricator to train them on filtering and gradient analysis. The training was demonstrated only at near normal angle-of-incidence. The result is plotted as such in the gradient figure.

2.2 Laser Damage Test

The basis for the laser damage threshold testing is found in LLNL specification[1]. This document provides a procedure tailored specifically for the evaluation of components for the NIF small optics program with several unique requirements. The procedure is driven by the need to assure a significant portion of the sample clear aperture is exposed to the test laser beam. By irradiating a large area it is assured that preferential damage sites, which can be randomly located in the coated sample, are located and exposed. Usually, a typical scan at a given fluence consists of over 2000 sites. Another difference is the overlap of the laser test beam and that the same area be tested for the next higher fluence level. This procedure simulates the laser conditioning effect that the optical coatings would experience in practice. Lastly a probable threshold is established which allows for acceptable laser damage to the coating. In comparison, the conventional procedure is to plot the percentage of the sites that failed as a function of fluence level. A linear regression analysis is performed and the threshold set at a failure rate of zero per cent.

The irradiation source used in these experiments is a commercial Nd:YAG laser system providing up to 500 mJ of laser energy in a 3.5 ns pulsewidth. The laser operates at a PRF of 10 Hz, with a >90 % fit to Gaussian beam profile in the far field. The laser energy is varied at the sample plane by using a 1/4 waveplate and thin film polarizer. The beam was focused using a telescope to provide a spot size on the far field on the order of 1 mm (1/e^2) diameter.

Laser beam diagnostics include pulsewidth, energy, and beam profile measurement. The pulsewidth is measured by observing the leakage through a 45° high reflecting mirror. A fast oscilloscope and 1gHz risetime detector is used to perform these measurements. The laser power is measured using a calibrated pickoff mirror and calorimeter. The beam profile is observed by placing a pickoff in the focused beam at near normal incidence. The profiling system is then positioned at the equivalent distance from the telescope to target.

Scanning the optic in the laser beam is performed using a set of motorized translation stages. The velocity of the stages is determined by the beam diameter at the target plane and the PRF of the test laser. The velocity is programmed to provide an overlap between pulses at the 90% energy level. By scanning at these levels the complete region is irradiated using the central or "peak" region of the Gaussian beam.

Laser induced changes to the optical surface are characterized by a high resolution vidicon camera equipped with a macro focusing lens. The camera is positioned such that the vidicon was observing the surface of the optic at a nominal magnification of 50x. The camera is equipped with a filter to reduce the infrared response and avoid observation of the 1064 nm pump beam. The camera is interfaced to a monitor and VCR to allow a videotape record of the irradiation procedure. A 5 mW Helium–Neon laser is aligned to overlap the damage beam at the target surface. The visible beam enhances the surface scatter and laser damage site formation allowing easy observation on a television monitor.

The LLNL test set-up was followed with the following major differences. The device used to measure the laser energy was a pyro-electric detector at LLNL and a calorimeter at the Laser Damage Test Service (LDTS). Also, a single-frequency injection laser was used at LLNL and a multi-mode laser was used at the LDTS. The former has a cleaner temporal shape compared to the latter laser system.

Three AR, three HR, and three polarizer coating sample witnesses were supplied to the LDTS for laser damage testing at 1064nm (nominally 3 ns pulse widths). The three samples of each coating type were selected to cover a range of damage thresholds for the coating type. The damage testing was with p-polarized light and at the use-angle of the coating. The LDTS was asked to determine the Qualified, Probable, and Failed damage thresholds on each sample according to the LLNL specification[1]. The definitions of Qualified, Probable, and Failed damage thresholds are the following:

The Qualified damage threshold means that up to the specified fluence, the optic showed no signs of damage. This definition matches that of the ISO 10110-13 definition of laser irradiation damage threshold[2].

The Probable damage threshold means that at the specified fluence one or more of the following occurs;
   1. change in the scatter above the noise limit and verified to be damage by microscopy,

2. visible pinpoint damage observed by the operator which is less than 100 μm, does not grow, and occurs in less than 1% of the sites.

The Failed damage threshold means that at the specified fluence, one or more of the following occurs

1. pinpoint damage at more than 1% of the sites,
2. pinpoint damage larger than 100 μm or,
3. damage which indicates growth upon further illumination (considered to be catastrophic damage).

The fluence is increased in increments of 3 J/cm^2 per area scan, and the measurement error in the power is +/- 1 J, pulse-width is 3.5 +/- 0.5 ns, and spot size is 1.15 +/- 0.05 mm. Given the incremental steps and measurement errors, an error box was drawn from the data points. The lower left hand corner of the box for Qualified thresholds originates at the data point. The upper right hand corner of the box originates for the Failed data points. The origin of the box for Probable data points depends whether there are lower fluences at the Qualified or Probable thresholds, and if there are higher fluences at the Failed threshold. If the box touches the correlation line, the data point was categorized as a correlated point.

3. RESULTS

3.1 Wavefront Correlation

The filtered rms values are plotted in Fig. 5. The average deviation from the CVOS result is 0.89%. The largest deviation is 8% from P7.3.0 operating on files 8022 and 8044, wavefront tests at the use-angle. These variations may have been caused by manual placement of the clear aperture mask before the analysis of the interferometric data file. All noted software versions appear to filter the interferometric data correctly. These results show that all analysis packages give similar filtered wavefront results.

The results of the filtered wavefront gradient analysis by the noted software applications are plotted in Fig. 6. The typical surface gradient specification is 21.1 rms nm/cm at the use-angle. In all cases, filtering reduces the measured gradient value by removing higher frequency gradients from the final result. When using the software-P versions, the gradients are on average within –1.0% of the CVOS value. The maximum deviation of 9% was P7.3.3 operating on file 8042. When using the software-U versions, the gradients are on average within 10% of the CVOS value. The maximum deviation of 32% was U6.7.9 operating on file 8031. When using the software-V version, the gradients are on average within 27% of the CVOS value. The maximum deviation of 34% was V2.2.1 operating on files 8031, 8034, and 8043. The software-P has the lowest average gradient deviation of the three software applications tested. The -software-U consistently yields lower gradients. This may be caused by the automatic selection of the filtering frequency by software-U. We were not able to fix the filtering at a 2 mm spatial period.

Although the V2.2.1 software appears to filter the data correctly, it does not appear to perform the gradient analysis correctly. To confirm this observation, a virtual optic was created electronically with a known gradient of 0.075 waves/cm. CVOS generated a gradient of 0.073 waves/cm and V2.2.1 reported a value of 0.026 waves/cm. This software glitch has been reported to the commercial software supplier.

In summary, U versions as old as 6.0.26 and P versions as old as 7.3.0 may be used to perform filtering and gradient analysis of NIF small optics. For other interferometer software versions that may require software evaluation, the four mirrors and data files are available. A simple procedure is if the analysis program can read data files that are saved by MetroPro® and stored on a CD. Another procedure for software verification would be to send one or more of the mirrors for measurement and analysis. This requires access time on the interferometer.
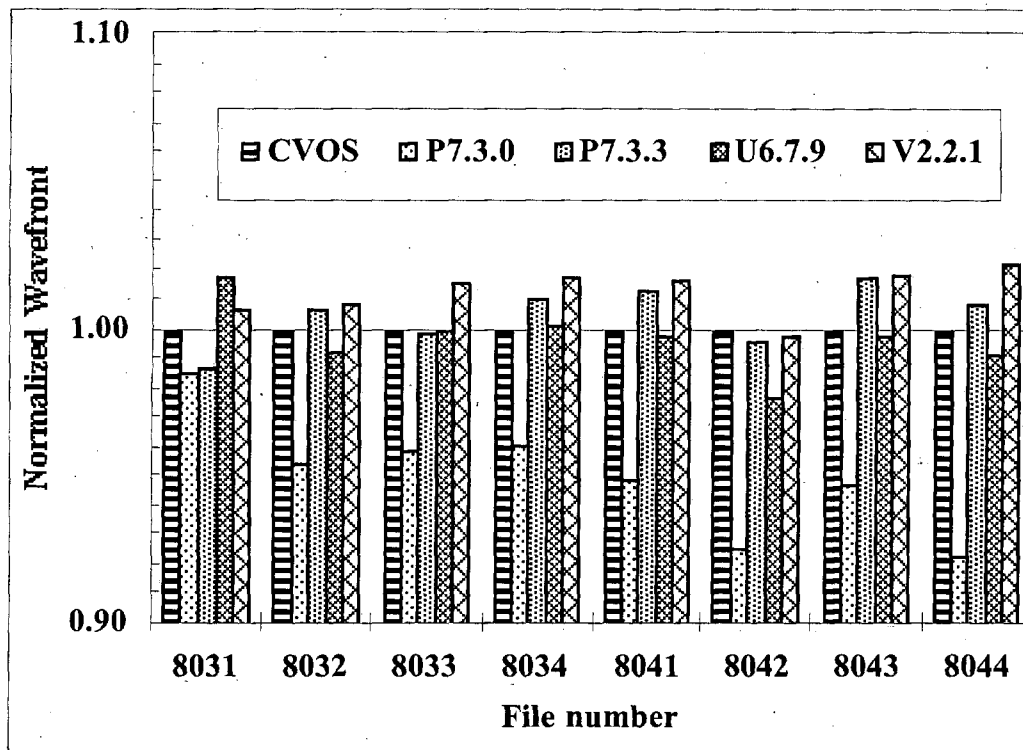
Figure 5. Filtered rms wavefronts normalized to the CVOS value. The filtering was done at 0.5 /mm. These results show that all analysis packages give similar filtered wavefront results. These high reflectors have rms wavefront below the rms specification of 9.0 nm rms at the use-angle (File numbers 8041, 8042, 8043, and 8044.
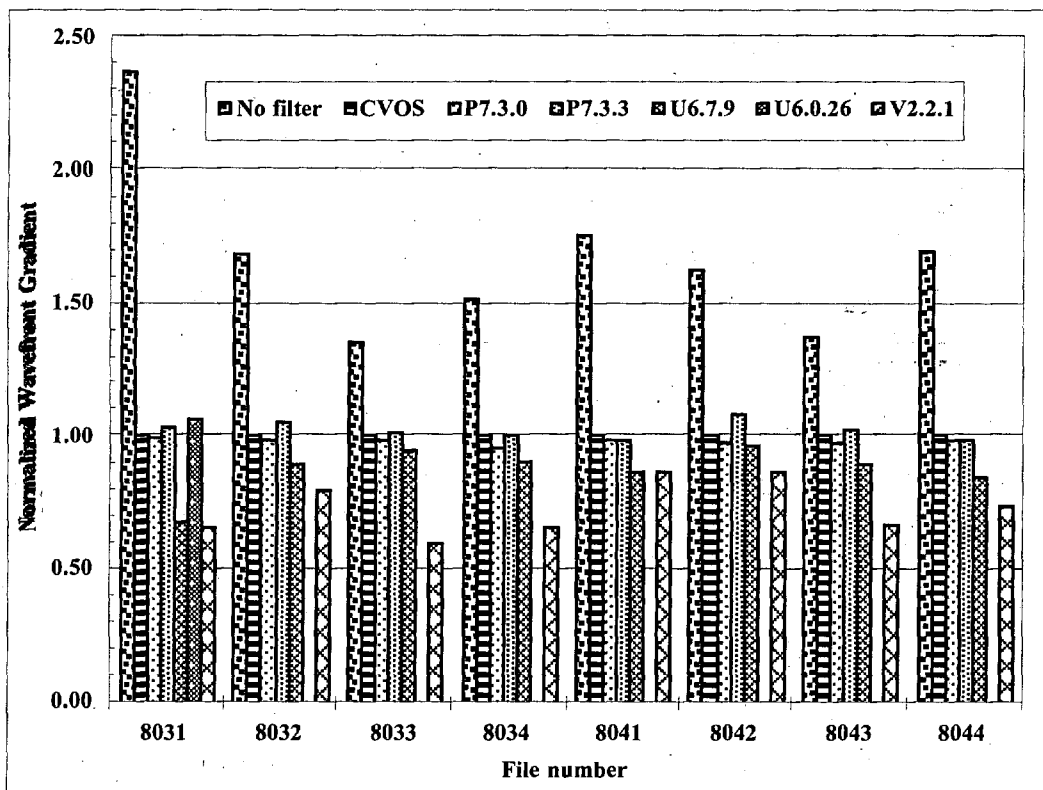

Figure 6. Filtered gradients normalized to CVOS values. A low-pass filter of 0.5 /mm was applied.

3.2 Laser Damage Correlation

Figures 7, 8, and 9 are the correlation plots between the NIF and the LDTS laser damage testing of anti-reflective (AR), high reflector (HR), and polarizer coatings, respectively, designed for 1053 nm. For the AR coatings, 7 of 9 data points fall on the correlation line. The other 2 data points from the LDTS are lower than that reported by the NIF Small Optics Test group (SOT). The AR samples were coated on both sides. The pump beam passes through the first surface of the optic and the laser damage occurs on the second surface of the sample due to self-focusing. The two Qualified thresholds which did not correlate may be caused by the random selection of different test areas with different absorptive defects. These could be defects in the coating[3], substrate, or at the interface between the coating and the substrate. Since the exposure of defects which are susceptible to laser damage depend on the portion of the test area, a larger test area may be required for determining the laser damage threshold of low-defect density AR coatings. However, the defect density of the coating may have some bearing on the laser survivability of the optic. The surface defect densities were determined by optical microscopy at a 200x power. The sample with the highest laser damage thresholds (the three levels of Qualified, Probable, and Failed) also has the lowest defect density.

For HR and polarizer coatings, all data points from the LDTS either correlate with or are less than that obtained by the SOT.
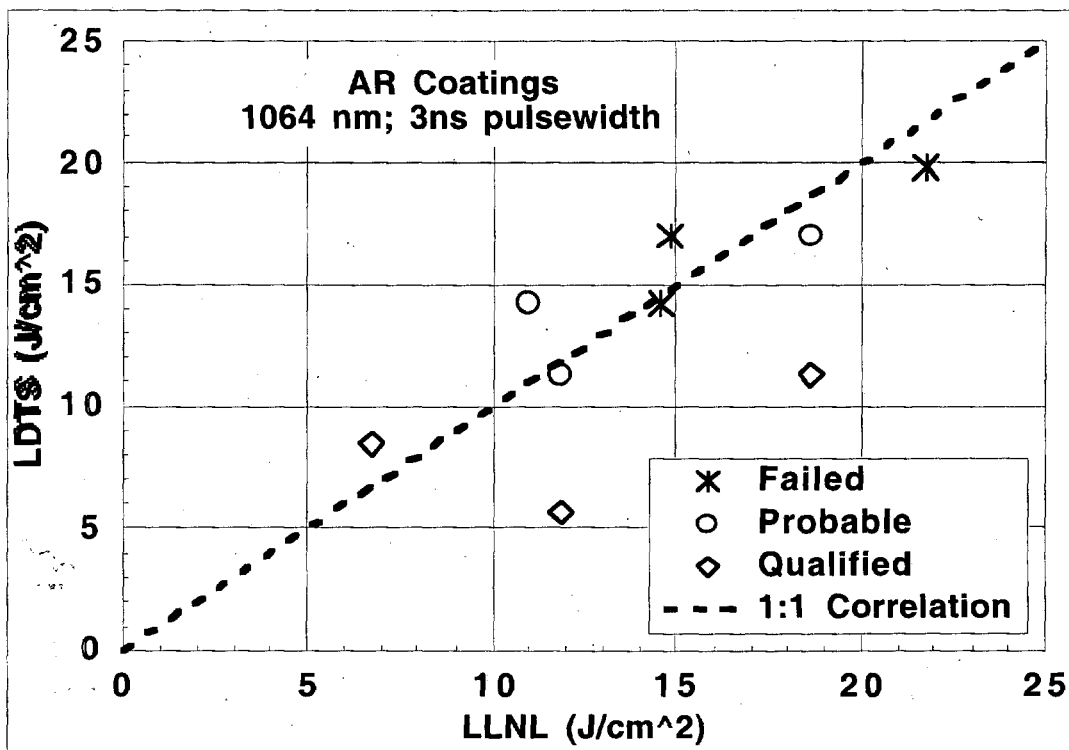

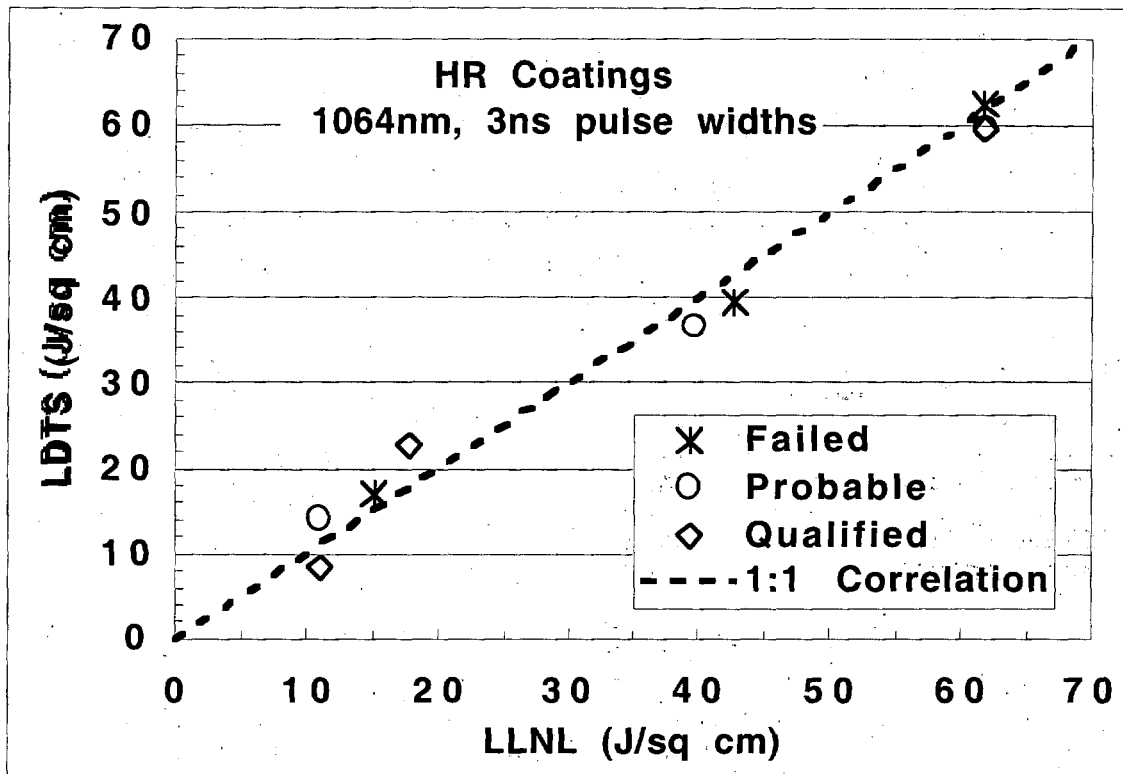Figure 7 Laser Damage thresholds of AR coatings.

Figure 8 Laser Damage thresholds of HR coatings. All 9 thresholds correlate within the experimental error.
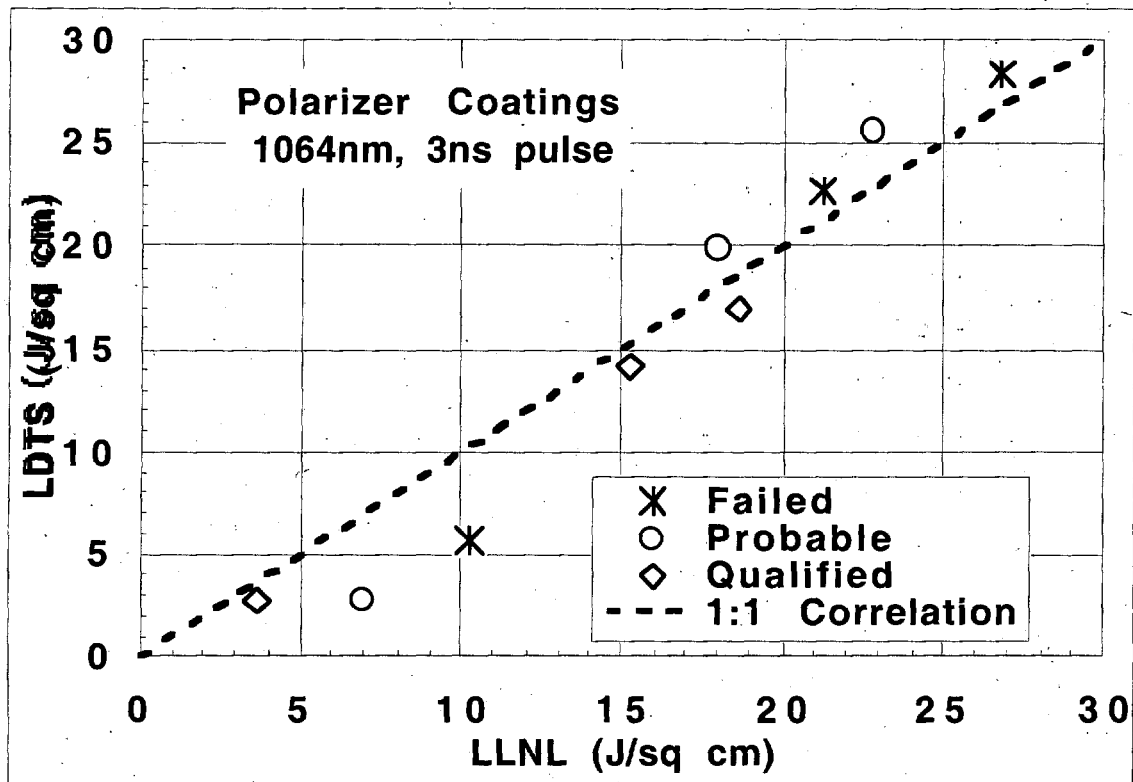

Figure 9 Laser Damage thresholds of polarizer coatings. All 9 thresholds correlate within the experimental error.

4. SUMMARY

The rms gradient specification requires two analysis steps: (1) Low-pass filter the wavefront and (2) Calculate the rms gradient of the result. The software applications P7.3.0, P7.3.0, U6.7.9, and U6.0.26 do both steps correctly as defined by CVOS results. The V2.2.1 software filters correctly but does not generate gradients that match those produced in CVOS.

The thresholds reported by the LDTS either correlate with the SOT data or are lower than that reported by SOT. The results from the HR and polarizer coatings correlate within experimental errors. The AR coating results either correlate or are less than that reported by the SOT group. The latter is an acceptable result for the project in that it is a conservative test. The data correlation between commercial and NIF project inspection equipment minimizes the fabricator's dependence on project resources and test equipment.

AUSPICES AND ACKNOWLEDGEMENTS

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3. R. Chow, J. R. Taylor, Z. L. Wu, "Absorptance behavior of optical coatings for high-averaged power laser applications," Appl. Optics 39(4), 1 Feb. 2000, pp. 650-658.